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EXECUTIVE SUMMARY

STUDY OF SPREAD SPECTRUM MULTIPLE ACCESS SYSTEMS FOR SATELLITE COMMUNICATIONS WITH OVERLAY ON CURRENT SERVICES

by Tri T. Ha and Timothy Pratt

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
BLACKSBURG, VA 24061

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VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
Blacksburg, Virginia 24061 (703) 961-6646

EXECUTIVE SUMMARY

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"A Study of Spread Spectrum Multiple Access Systems for Satellite Communications with Overlay on Current Service."

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Virginia Polytechnic Institute and State University, Blacksburg, VA 24061

1. Introduction

There are many applications for low cost satellite communication links in which a large number of small terminals send data at a low rate to a central terminal. This report describes two approaches to the design of such systems using spread spectrum techniques. Spread spectrum provides a means for multiple access of a single communication channel with low interference to other users; in this application, it is used to overlay a low data rate signal on top of an occupied channel.

The report discusses two different methods of generating spread spectrum signals for an overlay service, and examines the data rate and efficiency which can be achieved while maintaining low interference with existing traffic.

In the first part of the report, m-ary FSK is used as the spread spectrum technique. In this method, the signal is switched between a large number of frequencies and the average power density at any frequency is very small. In the second part of the report, chirp spread spectrum is described. In the chirp system, each data bit is sent as a series of frequency sweeps over a wide frequency range. This ensures that spectral density is low at any frequency.

Spread spectrum is an important technique in any satellite communication system using very small antennas (VSAT's). A small antenna has a broad beam, which results in interference at adjacent satellites in the geostationary orbit. If conventional multiple access techniques are used, such as FDMA and TDMA, the adjacent satellite interference may be excessive.

In the work reported here, the capacity and performance of VSAT links overlaid on an occupied channel were investigated, for the m-ary FSK and chirp systems. Results are presented showing how many channels can share a transponder, and the resulting interference levels. It is concluded that m-ary FSK is a good technique for multiple access by a number of small terminals. Its efficiency is higher than direct sequence spread spectrum systems, so more channels can be accommodated. Chirp spread spectrum is shown to be a simple technique for overlaying an occupied channel with a low data rate signal.

2. Multiple Access Using m-ary FSK

We investigated two forms of MFSK which incorporate spread spectrum techniques to reduce interference levels by spreading the spectral density of the signal over a wide range of frequencies. Part A of the report describes these systems and their performance in a VSAT network.

The two techniques investigated were MFSK/DS and MFSK/DS-FH. The first, MFSK/DS, converts data bits into a set of multiple frequencies, and the resulting signal is then multiplied by a pseudo-random (PN) sequence with a high bit rate to spread the signal energy over a wide bandwidth. In MFSK/DS-FH, the same frequency modulation is used initially, but the FSK signal is then frequency hopped at a high rate over a wide bandwidth to provide the required spectrum spreading.

In both cases, we investigated systems using non-coherent receivers because these are much simpler and cheaper than coherent receivers.

Figures 9A - 12A of the report show how many users can share a 36 MHz transponder at C band and Ku band. Each user sends a 1200 bps data stream, and a practical system needs an E_b/N_o of about 14 dB to achieve a satisfactory error rate at the receiver when non-coherent detection is used. It can be seen from these figures that the MFSK/DS/FDM systems achieve more channels/transponder than the MFSK/DS/FH systems, and that larger values of M lead to improved efficiency. This is because interference effects are reduced with high-order m-ary FSK.

We designed some typical links at C band and Ku band using these systems. Our typical VSAT systems used an antenna of 1.2 - 1.8 m diameter and transmitted 2W at C band and 0.5W at Ku band. The receiver used non-coherent detection, without coding. The bit rates were 1200 bps at C band and 56 kbps at Ku band. The resulting number of users in each system was about 1000 at C band, giving a transponder throughput of 1.2 Mbps, and around 50 at Ku band, for a throughput of 2.8 Mbps. This represents inefficient use of a 36 MHZ transponder; an efficient FDMA system could achieve at least 6.7 Mbps with 1000 users in a SCPC mode.

Interference levels at adjacent satellites with 2^o spacing were calculated at -100 dBW/m^2 for C band with 968 users and well below -112 dBW/m^2 at Ku band. The Ku band figure is acceptable, but the C band figure is too high for such a system to be employed when satellite spacing is 2^o. The broader beam of the C band antenna is the prime cause of the high interference level. This suggests that VSAT networks may be confined to Ku band operation when a large number of stations transmit simultaneously.

3. MFSK Overlay service

Overlay services place a low data rate signal over traffic in a channel which is already filled to its nominal capacity. Spread spectrum techniques allow the spectral energy of the overlay signal to be spread across the bandwidth so that the ratio of traffic energy to overlay signal energy becomes very high. Under these conditions, the overlay signal appears like low level noise to the receiver and normal operation of the channel is undisturbed. Obviously, very low data rates must be used in the overlay signal to avoid interference. Applications for such services are: a low data rate return signal overlaid on an outgoing television signal, engineer order wires, signaling channels to accompany TV or telephony, and other data communication links to accompany a broadband signal.

We have investigated the performance and capacity of MFSK-DS spread-spectrum overlay signals when the traffic is FDM or SCPC telephony, or FM-TV. The data rate which can be achieved for the overlay signal is in the 2.5 - 20 kbps range. Highest data rates are achieved by using convolutional encoding of the overlay data stream, and lowest interference is achieved with an FM-TV signal in the occupied channel. Interference ratios for the traffic channel were held to very low levels to guarantee zero impairment of the traffic.

4. Conclusions on Part A.

MFSK spread spectrum systems offer good multiple access capability and reasonable transponder utilization in a VSAT network. Efficiency is well below that achievable with SCPC or FDM/FDMA multiple access, but is much higher than for direct sequence spread spectrum multiple access. Interference levels at adjacent satellites are unacceptably high for a large network of C band terminals, but are tolerable at Ku band.

MFSK seems to be a good choice for a Ku band network of VSAT's operating at data rates up to 56 kbps. Using 1.8 m antennas and 0.5W transmitters, good performance can be achieved with a network of 60 to 80 terminals.

The advantages of MFSK spread spectrum are lower cost terminals and higher tolerance of interference.

5. Chirp Spread Spectrum

Chirp is a technique in which binary signals are represented by a rapid up or down sweep in frequency. The technique has been widely used in radars, but rarely for communications. In Part B of this report, we propose a system using multiple chirps to represent data 1's and 0's in an overlay service.

The major advantages of chirp as a spread spectrum technique lie in the ease with which the chirp signal can be detected (de-spread). In all other spread spectrum systems, a high-speed random (PN) sequence is used to spread the spectrum of the signal. At the receiver, a synchronization system must lock to the weak spread spectrum signal so that the incoming signal can be multiplied by a stored PN sequence, correctly synchronized, to achieve de-spreading. In low data rate systems, the time to lock a de-spreading sequence may be very long, and intermittent operation by terminals becomes impossible.

In a chirp system, de-spreading is achieved with passive dispersive filters, typically surface acoustic wave (SAW) devices, resulting in very much simpler receivers with no lock delay time.

Multiple access with chirp is poor when only the slope of the chirp signal is varied. To improve multiple access capability, we proposed a system which we call "Multi-Chirp", in which a sequence of fixed slope chirps is transmitted. The chirps can be up-or down-chirps, and various combinations of up and down slopes in a 16 or 32 bit word provide a means of identifying individual signals.

Multiple access performance with multi-chirp is well below that of the MFSK systems reported in part A, and we do not recommend chirp for this purpose.

6. Chirp Overlay Service

We investigated chirp for an overlay service in which data could be sent at a low rate over an FM-TV channel. The multi-chirp signal was designed to spread a 2.4 kbps data signal over 5 MHz bandwidth using a 16-chirp word of up and down chirps. A major difficulty which we encountered was a lack of published data on the spectrum of FM-TV signals. We simulated some typical and worst-case TV spectra so that we could assess the mutual interference problems for a chirp overlay system.

FM-TV presents a problem for a chirp overlay system. Chirp is a frequency modulation technique and an FM-TV receiver uses an FM demodulator to recover the TV signal. We simulated the response of a TV demodulator to a multi-chirp signal to assess the extent to which the overlay signal would cause interference, and were able to show that a 36 dB power ratio for

TV to overlay signal would result in unnoticeable impairment of the TV video.

The TV signals we used for overlay testing were a 9 step staircase and a random video waveform. Figures 10B and 14B show the time waveform and frequency spectrum of the staircase signal. Figures 18B and 22B show the waveform and spectra of the random signal. It can be seen that the random signal produces a much broader spectrum, representing a more difficult case for recovery of the overlay signal. Satellite TV systems use pre-emphasis with FM to obtain a S/N improvement in the video signal. We calculated new spectra for random signals after TV pre-emphasis had been applied; the result is shown in Figure 33B. The spectrum is now very broad and almost flat.

We used the random-waveform case to study mutual interference effects when a multi-chirp signal was overlaid on the satellite TV channel. We set the overlay signal power in the transponder to a level 36 dB below that of the TV signal, to ensure no impairment of the recovered video. We then varied the position of the 5 MHz wide chirp signal within the transponder band and calculated bit error rates for the data link. Figure 43B shows the results of this analysis. Placing the chirp signal in the center of the transponder leads to very poor performance due to the concentration of TV signal energy there. When the chirp signal is moved towards the edge of the transponder, acceptable error rates are obtained. Data rates up to 25 kbps are achievable when the chirp signal is located at the edge of the transponder band. With smaller frequency offsets, data rates of 2.4 and 4.8 kbps would be possible.

7. Conclusions

Low data rate systems using multiple chirp spread spectrum can be used to overlay an occupied channel. Analysis of FM-TV spectra shows that the chirp signal should be set 36 dB below the TV signal in the transponder to avoid TV impairment. Data rates of a few kilobits are then possible. At C band, a 350 mW transmitter and 2.4 m dish could send such a signal if the chirp RF frequency is offset at least 8 MHz from the video carrier.

Chirp systems have the advantage of a passive despreading circuit. There is no delay in synchronizing to the spread spectrum signal, which makes the technique attractive for short bursts of data. Applications in which terminals need to join a network briefly, send a few hundred bits of data and then leave the network, are well suited to chirp operation.

We conclude that chirp is a feasible technique for overlay service, although capacity of the overlay circuit is small. Performance of C band is good, with a low power transmitter and minimal adjacent satellite interference.

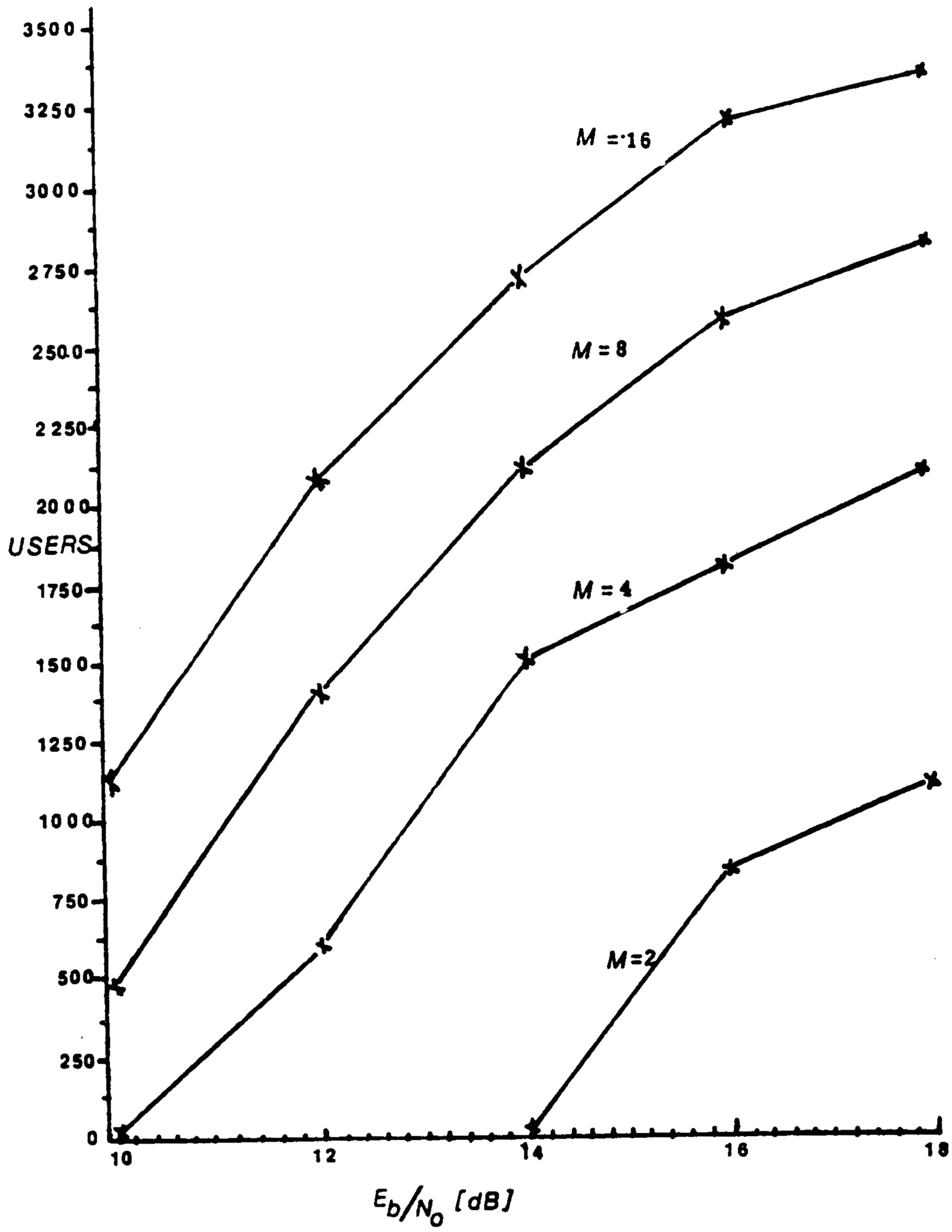

Figure 9A. Performance of MFSK/DS/FDM Systems (C band)

III. MFSK Spread Spectrum Multiple Access

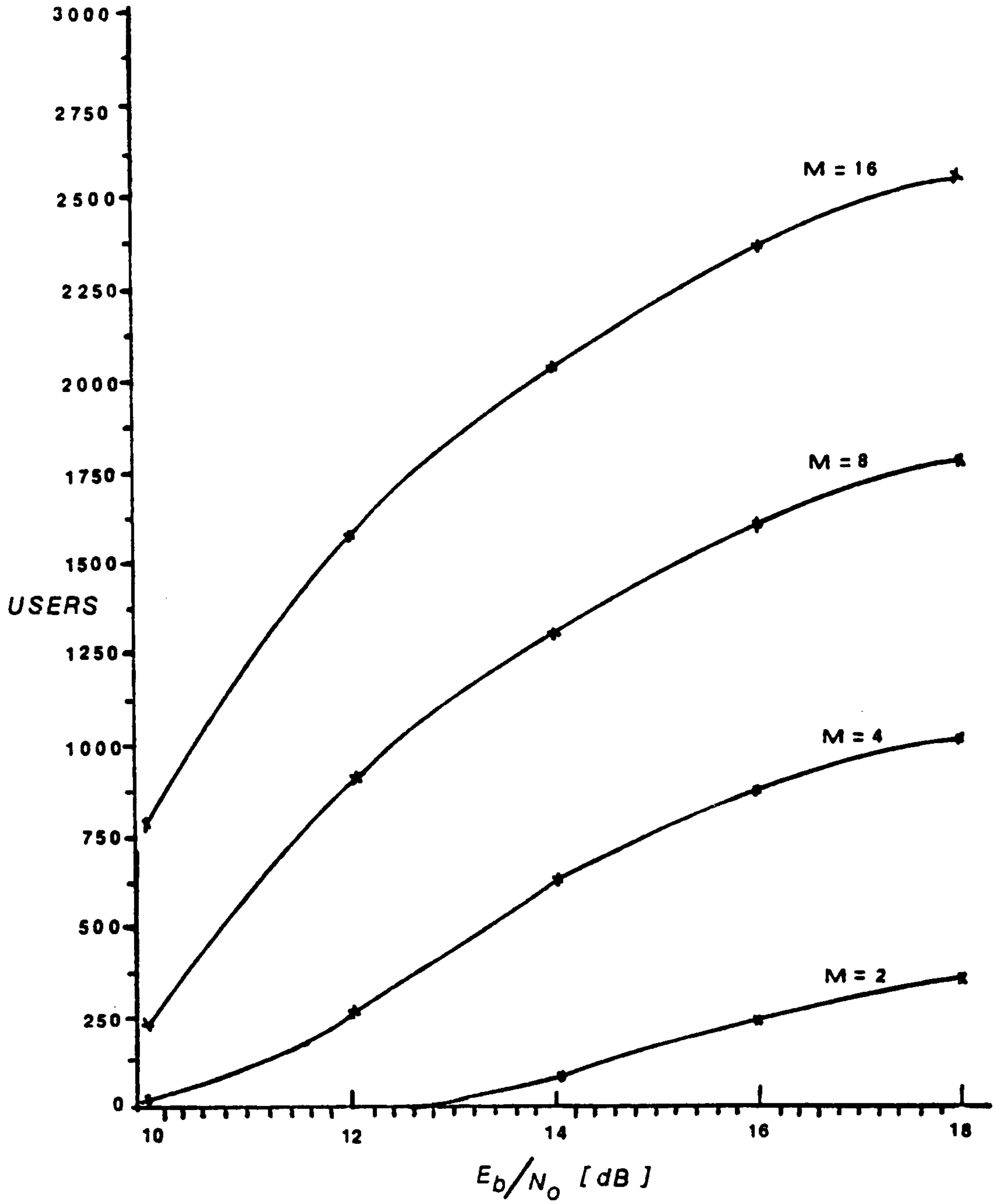

Figure 10A Performance of MFSK/DS/FH Systems (C band)

III. MFSK Spread Spectrum Multiple Access

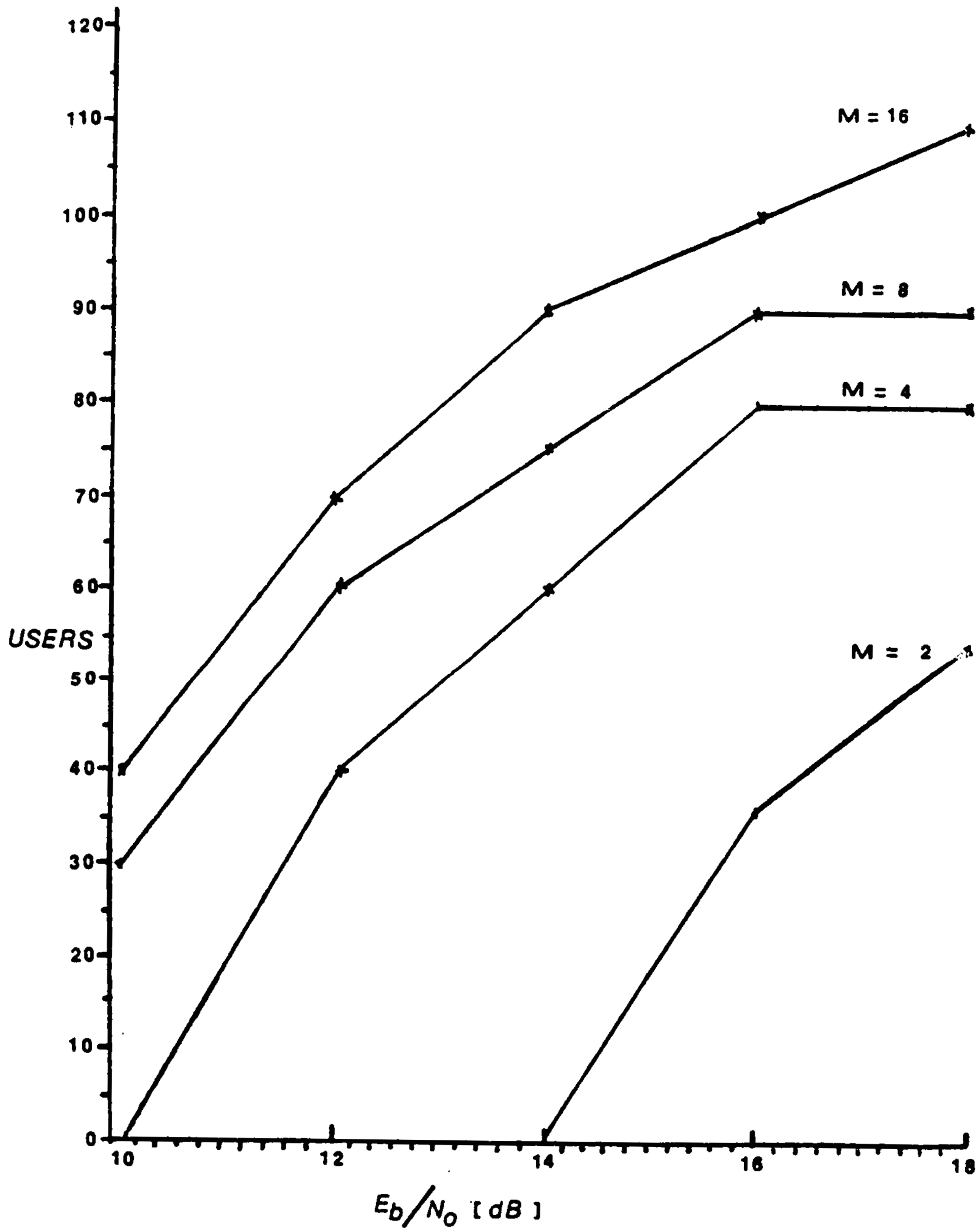

Figure 11A Performance of MFSK/DS/FDM Systems (Ku band)

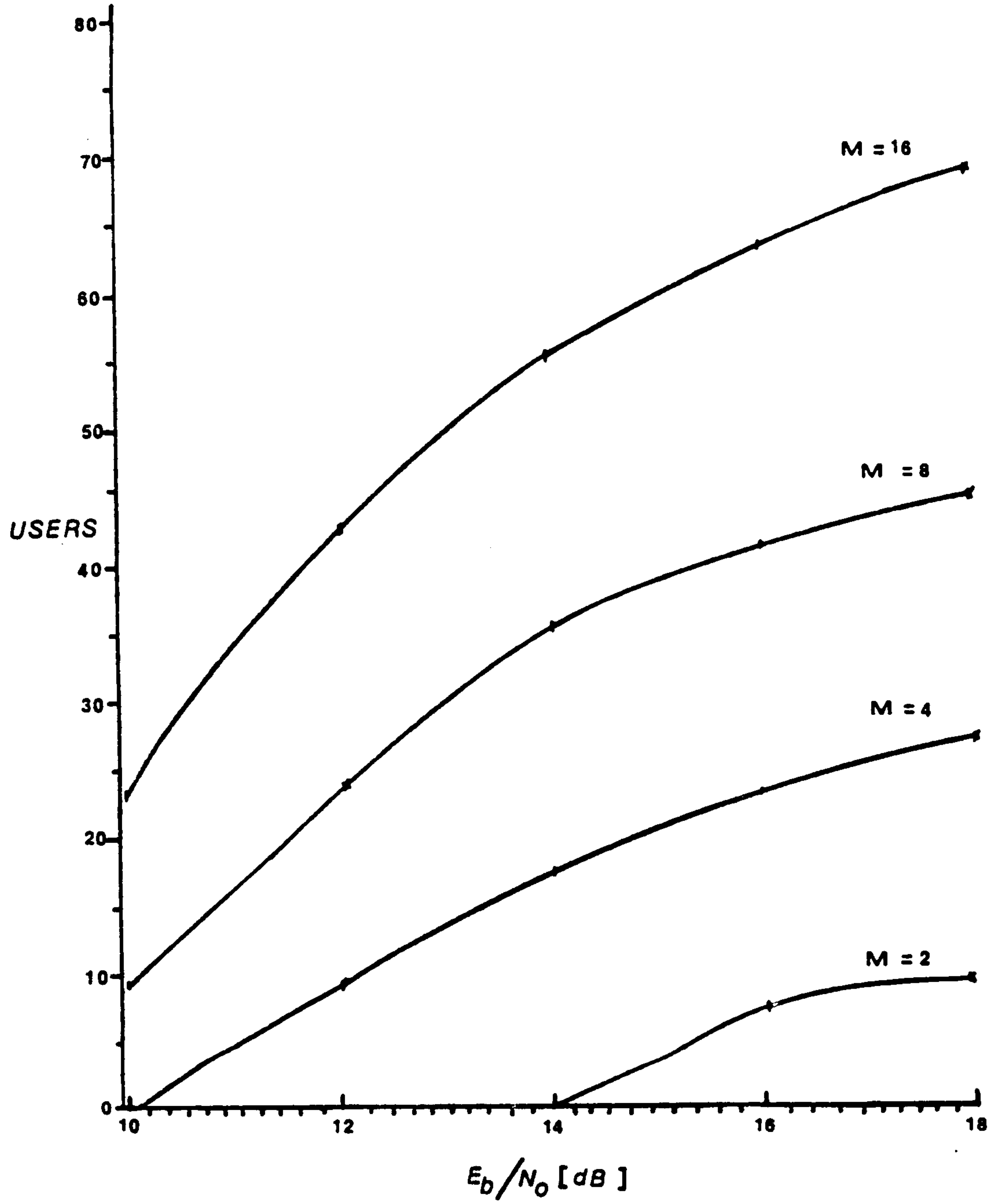

Figure 12A Performance of MFSK/DS/FH Systems (Ku band)

III. MFSK Spread Spectrum Multiple Access

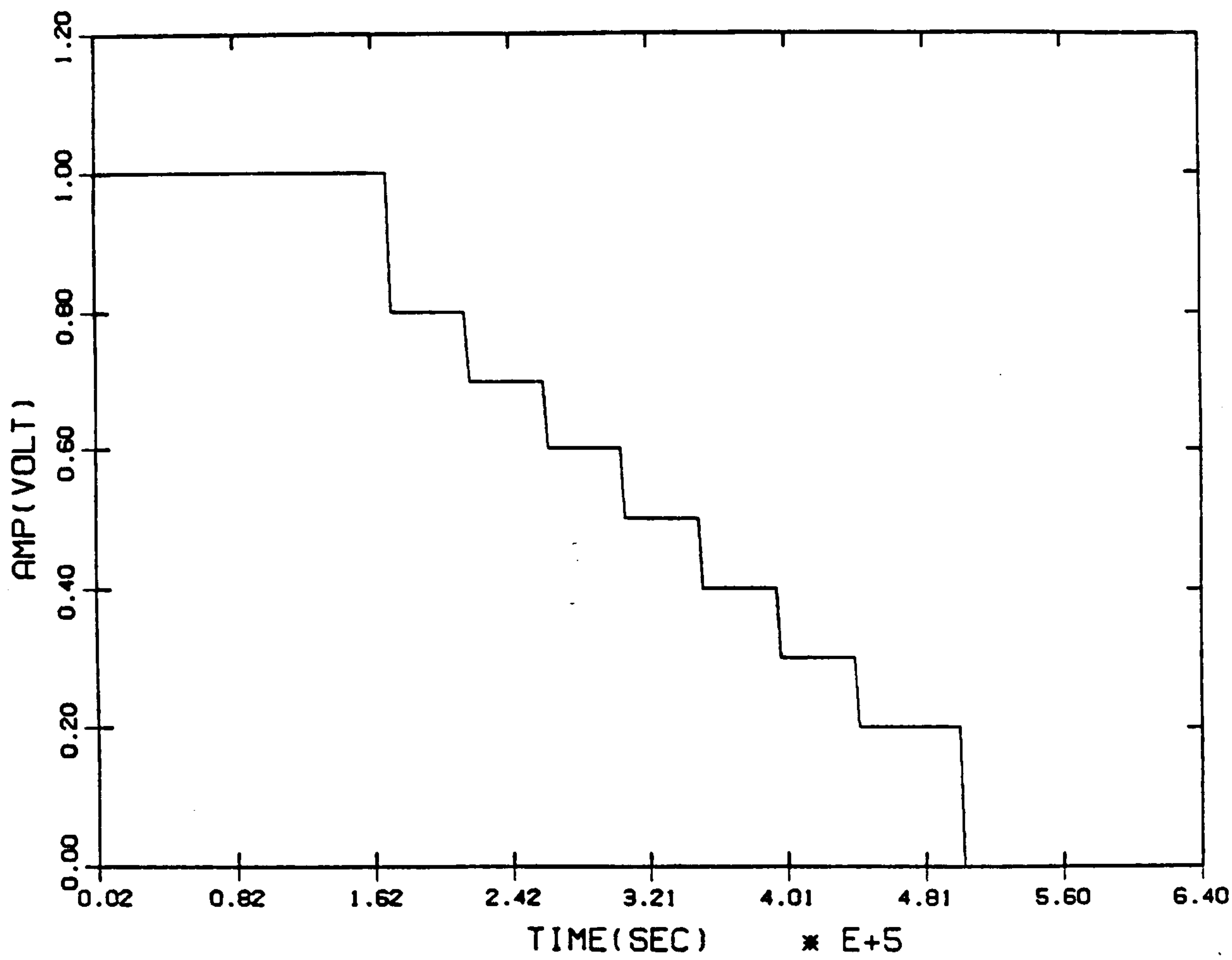

Figure 10B Simulated 9 step staircase function (time plot)

5. Interference Analysis I (General Approach)

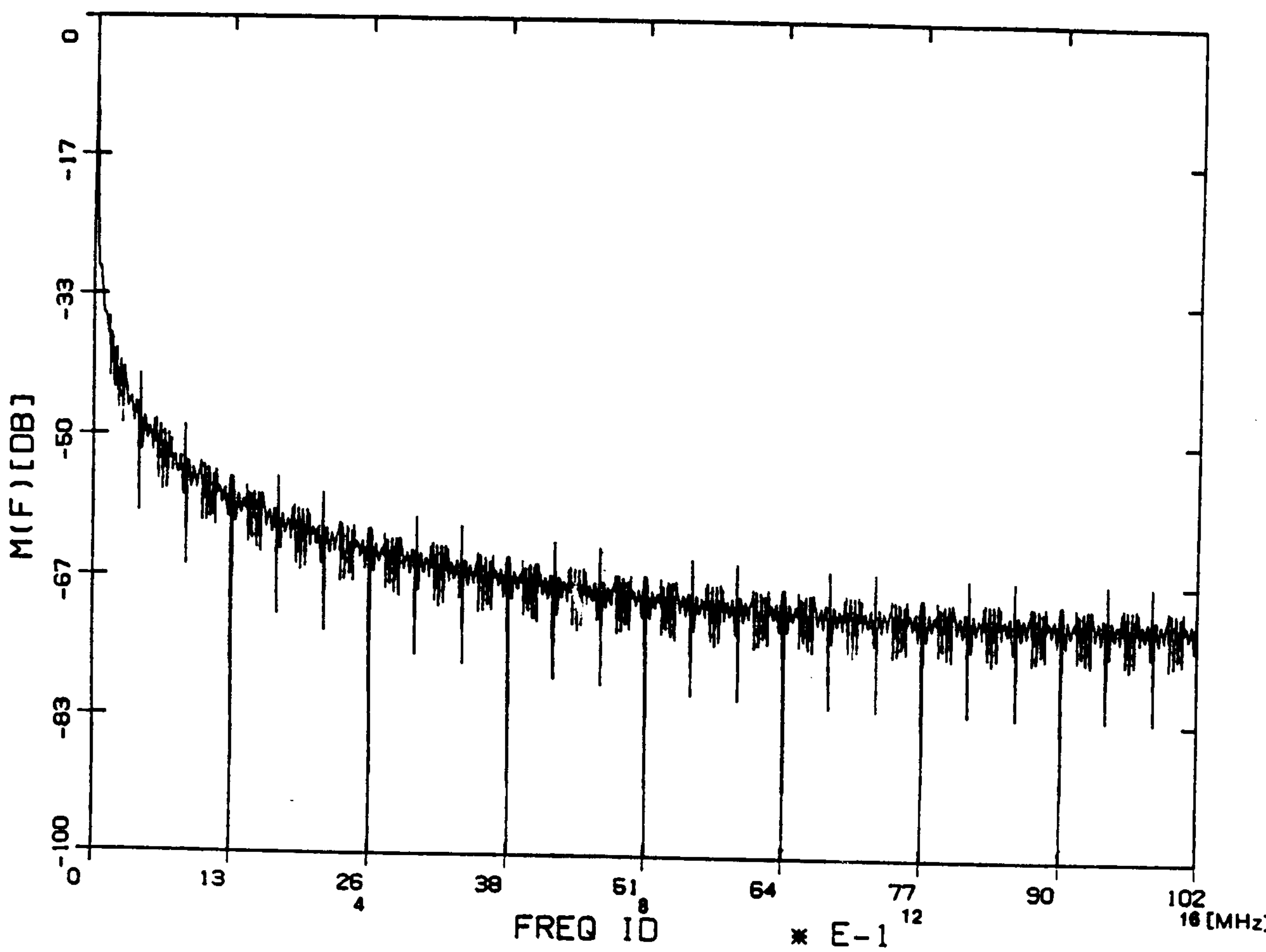

Figure 14B Spectrum of 9 step staircase function

5. Interference Analysis I (General Approach)

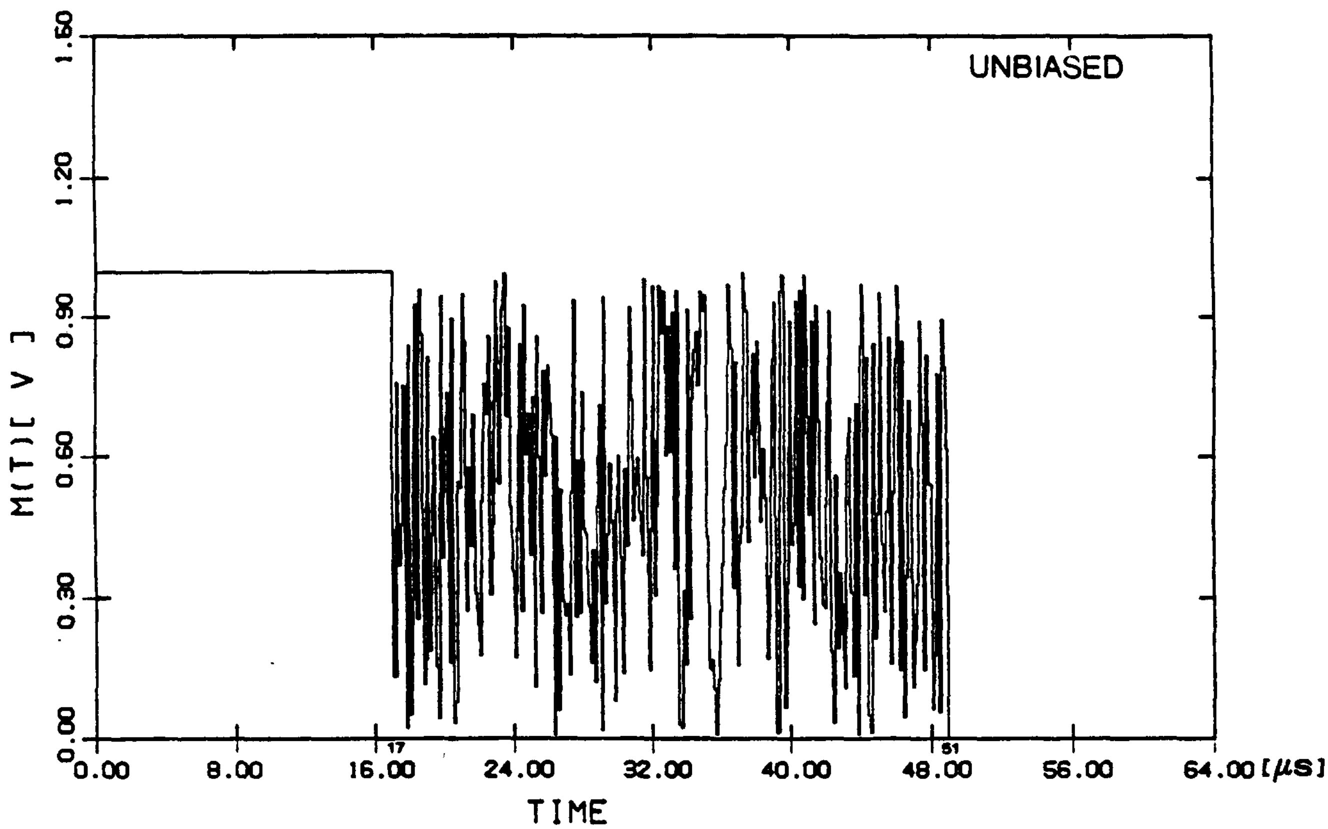

Figure 18B Time plot of simulated 256 step random amplitude model for video signal

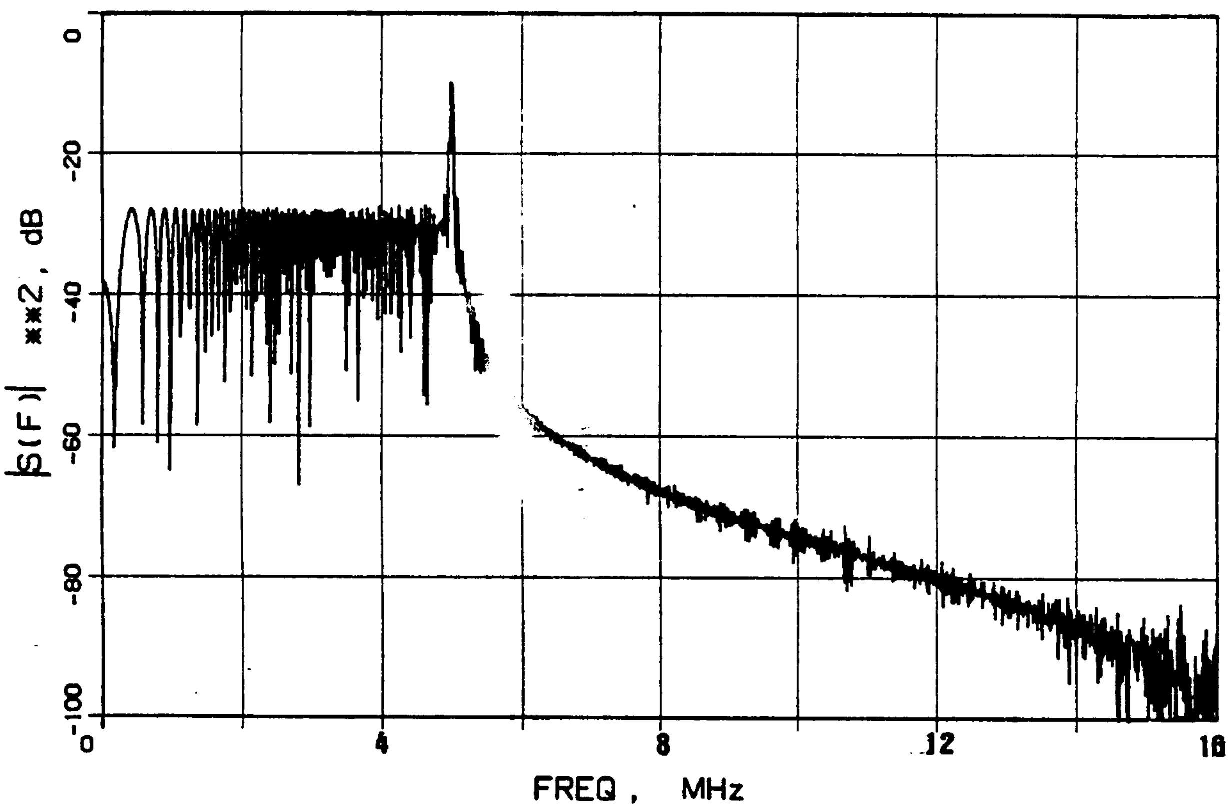

Figure 22B Frequency spectrum of figure 21 (linear)

6. Interference Analysis II (Practical Mcdeling and Simulation)

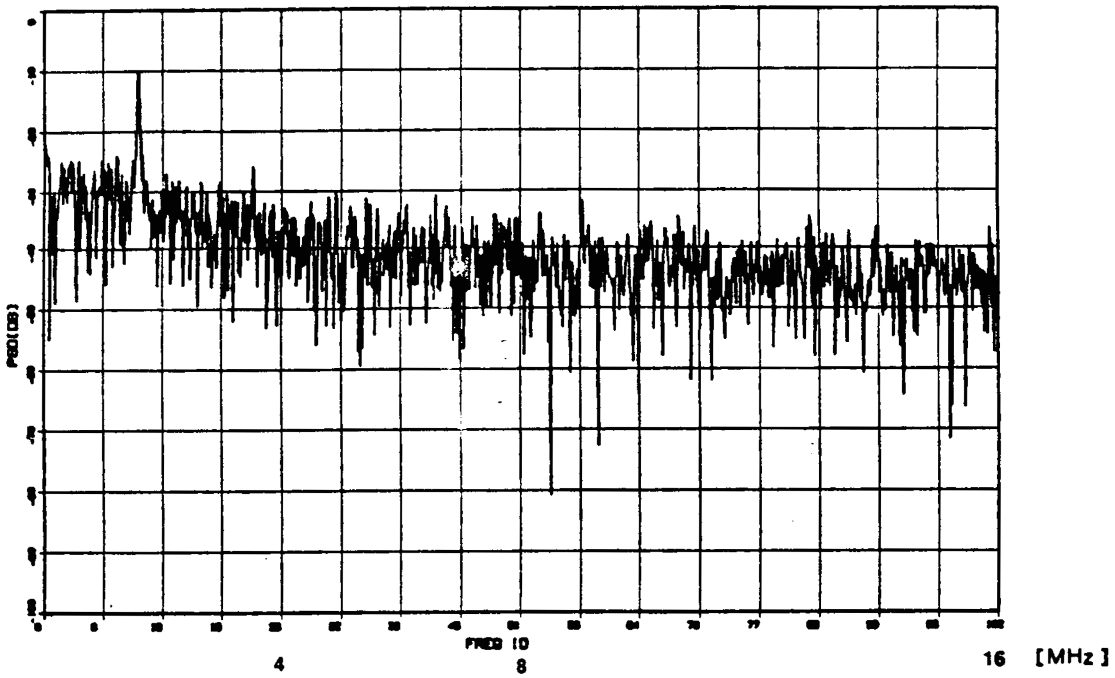

Figure 33B Transmitted FM-TV spectrum (m(t) = random, preemphasis version)

6. Interference Analysis II (Practical Modeling and Simulation)

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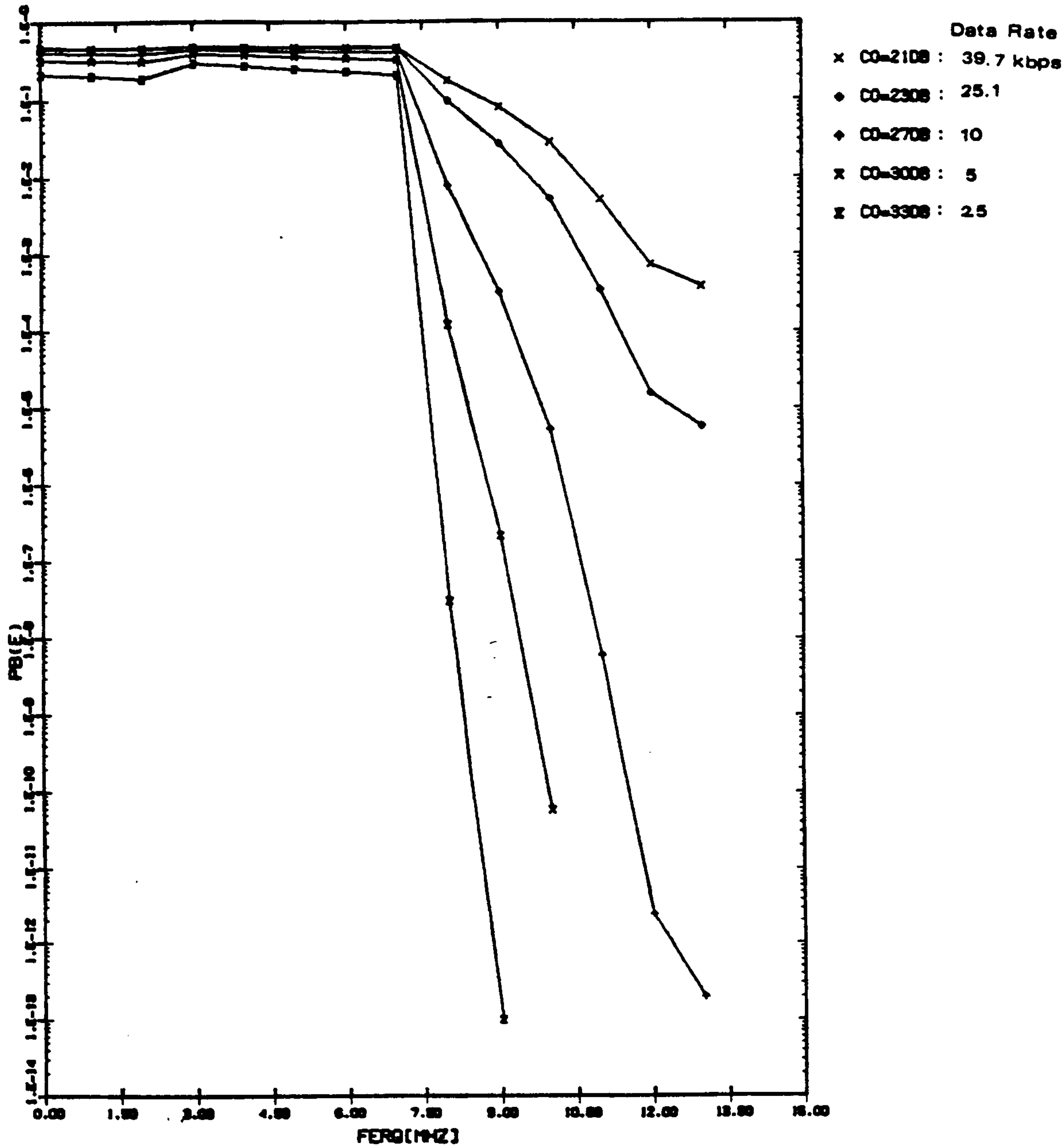

Figure 43B. Offset(IF) frequency vs chip error rate for some compression gains

8. Performance Analysis of Overlay Service II- Preemphasis Case.